SNOTEL WATER SUPPLY FORECAST AND INSTRUMENTATION DEVELOPMENT

ARS-SCS COOPERATIVE STUDY

Northwest Watershed Research Center
Northwest Area
Agricultural Research Service
U.S. Department of Agriculture
Boise, Idaho

Annual Progress Report No. 5

Cooperative Agreement No. 12-14-5001-6505

for FY 1985

To

Soil Conservation Service
U.S. Department of Agriculture

December 1, 1985

SNOTEL WATER SUPPLY FORECAST AND INSTRUMENTATION DEVELOPMENT

ARS-SCS COOPERATIVE STUDY

Northwest Watershed Research Center
Northwest Area
Agricultural Research Service
U.S. Department of Agriculture
Boise, Idaho

Annual Progress Report No. 5

Cooperative Agreement No. 12-14-5001-6505

for FY 1985

To

Soil Conservation Service
U.S. Department of Agriculture

December 1, 1985

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SNOTEL Water Supply Forecast and Instrumentation Development Study

Personnel Involved:

K. R. Cooley, Hydrologist	Plan, conduct, and report on hydrologic model evaluations.
A. L. Huber, Mathematician	Plan, conduct, and report on the water supply forecast research.
D. C. Robertson Hydrologic Technician	Assist in planning and conducting the hydrologic model evaluations.
M. D. Burgess Electronic Technician	Design, fabricate, test, and service any electronic instrumentation arising from this study.

SNOTEL Water Supply Forecast and Instrumentation Development Study

INTRODUCTION

The main emphasis of the cooperative research during fiscal year 1985 (FY85) consisted of developing methods for using SNOTEL data in the existing National Weather Service River Forecast System model (NWSRFS). The data base for the Lower Willow Creek, Montana basin was extended to include the 1973-1984 water years in order to provide a more substantial basis for evaluating the results of the various objectives. The calibration and test portions of the study were designed to be comparable to results produced by the USGS using the Precipitation-Runoff Modeling System (PRMS) for the same time period and basin.

An additional project was initiated to study the diurnal variability encountered in the SNOTEL precipitation gage readings during nonprecipitation periods. This project will consist of two phases. First, the data from over 500 SNOTEL stations will be analyzed to determine 1) which stations exhibit diurnal fluctuations, 2) if the fluctuations are correlated to temperature changes, and 3) if a relationship can be developed for correcting existing data. Second, a field study will be conducted wherein two sites will be intensively monitored to determine the nature of the instrumentation or installation problem. The work accomplished this year consisted of a preliminary analysis of one week's data from a few stations to establish criteria and methods for use in analyzing the 500 plus stations. Also, equipment for the field studies was ordered and preliminary selection of field sites was completed. A brief report concerning field experience with several types of climatological sensors was also completed.

OBJECTIVES

The objectives of the research conducted during fiscal year 1985, as outlined in the ARS-SCS cooperative workplan, are summarized as follows:

A. Conduct water supply forecast research using the National Weather Service River Forecast System model (NWSRFS) to:

  1. Expand the data base for Lower Willow Creek, Montana to include the 1973-1984 water years;

  2. Run the NWSRFS model using actual snow pillow data (in place of HYDRO-17 simulated snow water equivalent) to establish the melt plus rain file used in the SAC-SMA soil moisture accounting subroutine. Compare results with those produced using simulated data;

3. Run the NWSRFS model starting on January 1st, February 1st, and March 1st using the observed snow water equivalent on these starting dates, and actual precipitation and temperature for the forecast period;

4. After long-term calibration parameter values are established, change the SCF and PXADJ values for each year so as to produce simulated SWE values equal to observed SWE values on April 1st. The model will then be run for the forecast period using actual temperature and precipitation data. Results will then be compared to those produced using calibration SCF and PXADJ values; and

5. Compare results obtained by ARS with the NWSRFS model to those obtained by USGS using the PRMS model for the 1973-1984 period on Lower Willow Creek.

B. Summarize field experience relating to climatological sensors applicable for use at SNOTEL remote sites, gained from the research at Upper Sheep Creek, Idaho study site. This may include 1) soil moisture, 2) humidity, 3) wind run, and 4) pressure transducers.

C. Determine the magnitude, source, and possible solutions to the problem of diurnal variations in SNOTEL pressure transducer readings by:

1. Using 2-3 weeks data furnished by SCS, analyze the scope of the fluctuations at each site and determine the relationship of the fluctuations with ambient air temperature; and

2. Develop field experiments to check the standard SNOTEL transducers, precision DRUCK model PTX 160/D transducers, and transducers and equipment at typical sites including a SNOTEL site and a Bureau of Reclamation site, for temperature sensitivity.

Section I NWSRFS Model Updating and Use of SNOTEL Data

A. Site Description

The Lower Willow Creek Watershed near Hall, Montana encompasses an area of 73.3 square miles above the reservoir (Figure 1). Elevation ranges from about 4700 feet above mean sea level at the dam, to over 7900 feet elevation at the highest point. Average annual precipitation varies from approximately 14 inches at the lower elevation to over 30 inches at the higher elevations. Inflow records are available for portions of each year from 1967 through 1984.

Two SNOTEL sites are located on the watershed. The Combination site is located at an elevation of about 5600 feet. Records of snow water equivalent (butyl pillow) data are available for the 1973-1984 period, and precipitation data are available for the 1979-1984 period. The Black Pine site is at an elevation of about 7100 feet. Records of snow water equivalent cover the period 1966 through 1984, while precipitation records are available for only the 1979-1984 period.

National Weather Service climatological records are available for three stations within the general area of the Lower Willow Creek Watershed, but all three are located outside of the watershed boundaries. The three stations are: Drummond, Philipsburg, and Silver Lake. Drummond is located approximately 10 miles northeast of the watershed at an elevation of 3943 feet. Precipitation and air temperature records from Drummond are the most complete of the three stations for the period of interest. Philipsburg is about 7 miles from the southern end of the watershed at an elevation of 5270 feet. Both precipitation and air temperature records are quite complete for the period of interest from Philipsburg. The Silver Lake station is about 18 miles from the southern end of the watershed at an elevation of 6480 feet, and only precipitation records are available.

In order to address the objectives listed above, it was first necessary to enter the 1984 water year precipitation, temperature, and runoff data into the data files. Some of the data was entered by USGS in Denver and sent to ARS in Boise on magnetic tape. The data was also entered in Boise, and the two data sets were cross-checked to eliminate possible errors. All of the input data was entered twice, error checked, and converted to proper units and formatting for use with the NWSRFS model.

B. Calibration and Tests

After all data sets were ready, it was necessary to determine the parameter values for the 1973-1978 calibration period. In the previous year (FY84), two calibrations were conducted. The first, involved only the HYDRO-17 snow model which was calibrated against snow pillow snow water equivalent (SWE) data at the Combination and Black Pine sites. The second, involved the HYDRO-17, Sacramento soil moisture accounting, and the unit hydrograph portions of the NWSRFS model, and streamflow was used

Figure 1. Lower Willow Creek Watershed near Hall, Montana.

as the basis for calibration. This year, only streamflow was used for calibration purposes since the main emphasis of this study was to determine if the NWSRFS model could be used to assist in making water supply forecasts, and if the real time SNOTEL data would improve forecast results.

The cessation of the Silver Lake Ranger Station data collection, at the end of the 1983 water year, required alteration of the procedure previously used. In prior studies Silver Lake precipitation was used to represent precipitation in the upper zone (above 6100 feet elevation) of Lower Willow Creek. However, since the goal of this study was to use six years for the calibration period and six years for the test period, only Drummond and Philipsburg records were adequate. Previous analysis indicated that Drummond data provided both a more complete record and a better correlation with the short record precipitation on the Lower Willow Creek basin. Therefore, the precipitation and temperature data from Drummond were used in both the calibration and test periods as input to the model for determining mean areal temperature and mean areal precipitation for both zones.

Monthly, annual, and average monthly precipitation for the Drummond weather station are presented in Table 1 for the 1973-1984 period. In order to derive relationships between precipitation at Drummond and the snow pillow sites, the precipitation data collected at the pillow sites, after the 1979 gage installations, was used. Monthly and annual precipitation for the Combination and Black Pine sites are presented in Tables 2 and 3, respectively, along with the ratios to long-term Drummond precipitation data.

Since the monthly ratios varied considerably during the year, it was decided that seasonal ratios would be more realistic than average annual values. However, it is not possible to change parameter values during the year without stopping a run, re-initializing parameters, and starting again at the stopping date. It was therefore decided that PXADJ would be selected to represent the summer ratio between the snow pillow sites and Drummond precipitation. The SCF parameter would then be used to adjust for the increased ratio noted for the winter period when precipitation would be predominately snowfall. The SCF parameter is therefore raised above its normal range to account for snowfall loss from unshielded gages and to represent the greater seasonal ratio noted for the winter period.

Other initial parameter values used in the model were based on actual data when possible, i.e., potential evapotranspiration was based on data from Bozeman, Montana. The final parameter values used in the calibration and test periods are presented in Table 4.

The observed and model simulated runoff traces for the 1973-1978 calibration and 1979-1984 test years are presented in Figures 2 and 3, respectively. The calibration results are typical of those obtained when parameter values are held constant during multi-year model runs. In these cases, simulated runoff values are observed to be low some years, high some years, and about the same as observed other years. In general, simulated values of runoff match observed values better during the calibration period than during the test period. Simulated runoff volume

Table 1. Monthly precipitation (inches) at Drummond, Montana weather station - elevation 3943 feet.

Month	Year												Monthly Average
	73	74	75	76	77	78	79	80	81	82	83	84	
J	0.14	0.85	1.10†	0.88	0.94	1.10	0.84	1.00	0.08	1.85	0.49	0.77	0.84
F	0.19	0.42	0.95	1.07	0.07	0.63	0.80	0.80	0.94	1.21	0.51	0.24	0.65
M	0.45	1.26	0.64	0.43	0.77	0.57	1.28	0.94	0.79	2.38	0.66	1.15	0.94
A	0.48	0.68	2.81	1.24	0.01	0.84	0.76	1.50	0.48	1.17	0.74	1.87	1.05
M	0.84	1.05	2.40	1.13	1.98	1.74	0.60	6.01	3.31	1.41	1.79	1.03	1.94
J	1.59	1.57	2.19	2.58	0.63	1.16	0.23	3.76	1.75	2.18	2.08	1.68	1.78
J	0.06	0.85	2.40	0.74	1.15	1.45	0.04	1.35	2.46	1.70	2.47	0.30	1.25
A	0.48	0.95	2.93	1.59	0.84	1.46	1.62	1.39	0.76	0.76	1.76	2.35	1.41
S	1.62	0.84	0.72	1.16	1.27	1.78	T	1.39	0.63	1.22	2.00	0.64	1.11
O	0.51	0.38	3.23	0.34	0.68	0.01	0.27	1.06	1.79	1.26	0.85	*	0.94
N	1.40	0.81	1.49	0.23	0.85	1.24	0.16	0.49	0.77	0.30	0.62	*	0.76
D	1.26	0.64	1.19	0.28	1.91	1.00	0.55	0.93	1.13	1.03	1.19	*	1.01
Annual total	9.02	10.30	22.05†	11.67	11.10	12.98	7.16	20.62	14.89	16.47	15.16	10.03*	13.76

† Used Philipsburg data.
* Missing data.

Table 2. Monthly precipitation (inches) at Combination snow pillow site and ratio of Combination precipitation to Drummond weather station precipitation - elevation 5600 feet.

Month	Year 79	80	81	82	83	84	Monthly Average	Combination / Drummond Long term
J	*	2.4	0.6	3.2	0.7	1.0	1.58	1.88
F	1.3	0.7	1.1	1.5	0.5	1.1	1.03	1.58
M	2.0	1.3	1.6	2.6	1.9	1.2	1.77	1.88
A	2.0	2.0	1.3	2.3	1.7	2.0	1.88	1.79
M	0.4	6.7	4.6	2.9	1.3	2.7	3.10	1.60
J	1.2	4.7	2.7	2.5	3.3	3.5	2.98	1.67
J	0.2	1.7	0.5	1.6	2.7	0.7	1.23	0.98
A	1.3	0.9	0.2	0.9	2.4	1.7	1.23	0.87
S	0.2	2.1	2.1	3.5	3.3	2.9	2.35	2.12
O	1.0	1.8	2.2	1.3	1.7	*	1.60	1.70
N	0.6	2.1	1.3	1.7	2.0	*	1.54	2.03
D	1.2	1.3	2.7	1.4	2.5	*	1.82	1.80
Annual total	11.4*	27.7	20.9	25.4	24.0	16.8*	22.11	1.61
							MAY-OCT	1.50
							NOV-APR	1.83

* Missing data.

Table 3. Monthly precipitation (inches) at Black Pine snow pillow site and ratio of Black Pine precipitation to Drummond weather station precipitation - elevation 7100 feet.

Month	Year 79	80	81	82	83	84	Monthly Average	Black Pine / Drummond Long term
J	*	3.6	0.7	4.5	1.5	1.9	2.44	2.90
F	*	1.4	2.6	2.9	1.7	1.8	2.08	3.20
M	*	2.5	2.9	3.7	2.3	4.3	3.14	3.34
A	*	2.7	1.4	3.5	2.3	3.0	2.58	2.46
M	0.8	7.9	6.8	2.5	3.5	3.4	4.15	2.14
J	0	5.2	2.7	2.9	5.3	3.8	3.32	1.87
J	0	1.2	0.7	1.3	2.9	0.6	1.12	0.90
A	1.8	1.2	0.3	0.9	2.2	2.8	1.53	1.09
S	0.1	1.2	1.3	3.3	2.6	2.3	1.80	1.62
O	1.0	3.8	2.2	1.9	1.6	*	2.10	2.23
N	0.9	1.6	2.0	1.4	1.8	*	1.54	2.03
D	1.9	1.3	3.7	3.3	3.0	*	2.64	2.61
Annual total	6.5*	33.6	27.3	32.1	30.7	23.9*	28.44	2.07
							MAY-OCT	1.64
							NOV-APR	2.76

* Missing data.

Table 4. Parameter values used in the NWSRFS model during calibration and test periods.

		Lower Zone Combination	Upper Zone Black Pine
SNOW-17			
PXADJ		1.50	1.70
SCF		1.25	2.10
MFMAX	(mm/°C/6 hr)	1.37	1.27
MFMIN	(mm/°C/6 hr)	0.50	0.40
UADJ	(mm/mb)	0.01	0.10
SI	(mm)	400	900
NMF	(mm/°C/6 hr)	0.18	0.18
TIPM		0.21	0.25
MBASE	(°C)	0.0	0.0
PXTEMP	(°C)	0.0	0.0
PLWHC		0.06	0.05
DAYGM	(mm)	0.10	0.10
ADC		B	A
SAC-SMA			
PXADJ		1.00	1.00
PEADJ		1.00	1.00
UZTWM	(mm)	50	40
UZFWM	(mm)	40	30
UZK		0.43	0.43
PCTIM		0.01	0.01
ADIMP		0.01	0.025
RIVA		0.03	0.03
EFC		0.3	0.50
ET-DIST		UNIFORM	UNIFORM
PBASE	(°C)	5.6	5.0
ZPERC		48.0	48.0
REXP		2.0	2.20
LZTWM	(mm)	160	160
LZFSM	(mm)	75	75
LZFPM	(mm)	150	150
LZSK		0.065	0.057
LZPK		0.005	0.005
PFREE		0.3	0.30
RSERV		0.3	0.30
SIDE		0.00	0.00

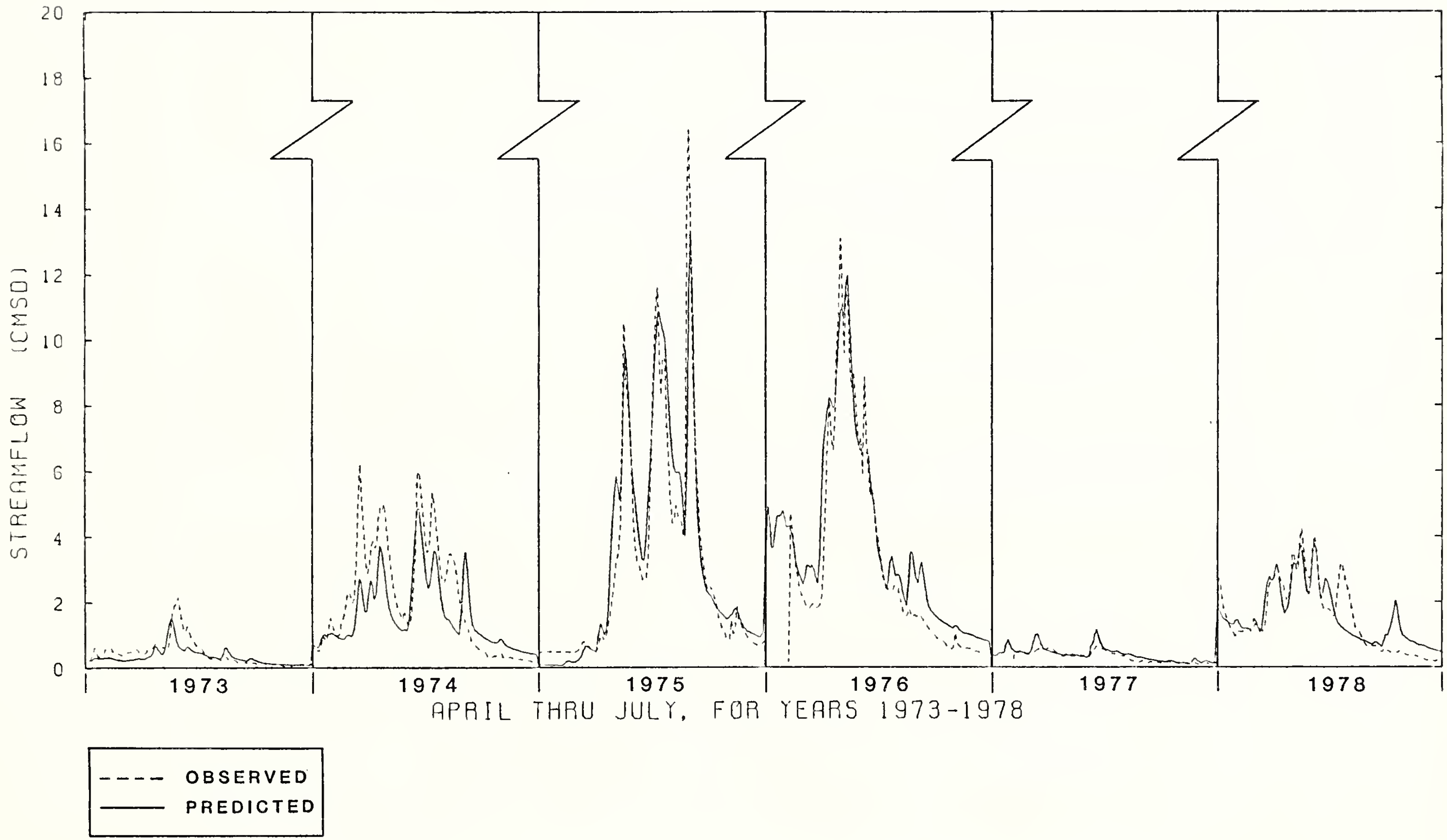

Figure 2. April through July observed and simulated streamflow at Lower Willow Creek, Montana for the 1973-1978 calibration period.

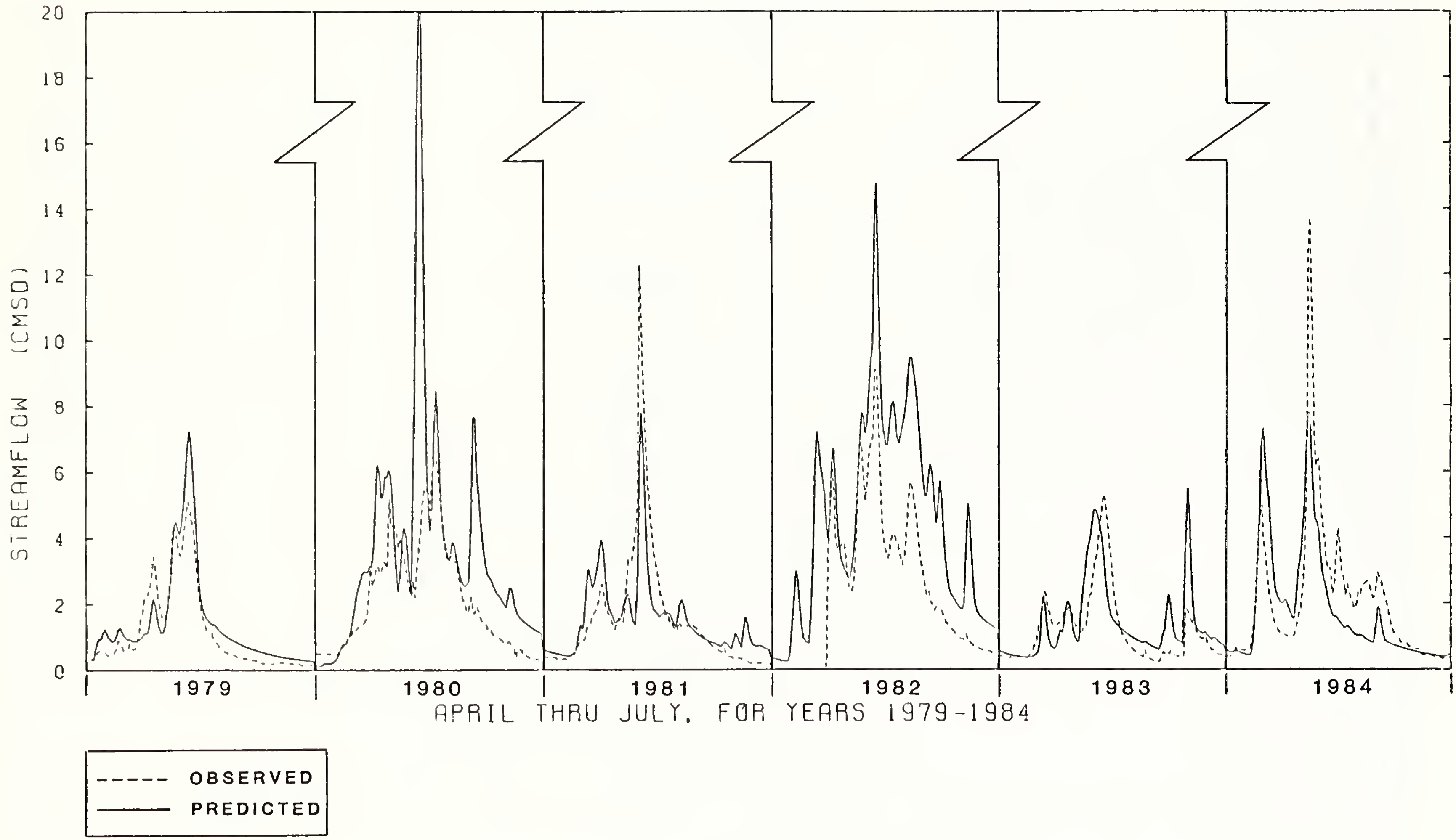

Figure 3. April through July observed and simulated streamflow at Lower Willow Creek, Montana for the 1979-1984 test period.

was greater than observed runoff volume during all of the test years except 1984. The magnitude of the overprediction during the test period tended to be greater than the differences noted for the calibration period. These differences could be due in part to a change in the relationship between precipitation on the basin and that at Drummond during the two six year periods. Unfortunately, data is not available prior to 1979 to provide verification.

Statistical measures of the goodness of fit of the simulated to observed runoff are presented in Table 5 for all periods of each year when observed runoff was recorded. Generally the period of observed runoff extended from April 1st through September or October. However, there was some variation in the length of record from year to year. Also listed in Table 5 are observed and simulated runoff volumes and differences between the two, for the April through July period. Since observed runoff data was not available for the entire year it was difficult to calibrate the model with respect to baseflow. Therefore, emphasis was placed on matching the main spring runoff which occurred during the April through July period. As noted, results are somewhat better for this comparison.

Although differences between observed and simulated runoff volume are rather large some years, the timing of major events (peaks) normally produced by spring snowmelt, is in quite close agreement as shown in Figures 2 and 3. One problem noted several times during the summer or fall (late June through September) was the appearance of a simulated runoff event when there was no indication of a change in observed runoff. These simulated events seem to be produced by thunderstorm rainfall recorded at Drummond and simulated by the model (when adjusted by PXADJ) to be significant enough to produce runoff from rainfall. Since there is no indication of an observed event, the storms either did not occur on the watershed or they were not of sufficient magnitude to produce overland flow and a change in streamflow. These descrepancies serve to emphasize the need for on-site precipitation data to improve model results.

C. Simulating Observed Snow Water Equivalent (SWE) on April 1st by Adjusting the Snow Correction Factor (SCF)

Calibration values of the snow model parameters SCF and PXADJ were based on relationships between seasonal precipitation volumes at the snow pillow sites and Drummond. If these relationships changed from year to year because of variations in storm tracks, inversions, or other meteorological conditions, this could affect yearly simulation accuracy based on long-term averages. A possible method of accounting for this variability consists of adjusting the values of SCF and/or PXADJ each year while holding all other parameter values fixed. Changes to SCF and PXADJ would alter the volume of water available for runoff, but would not affect the physical processes simulated by the model or the watershed characteristics established during calibration. In this case, only SCF was adjusted since comparisons were made on spring runoff which was mainly produced by snowmelt. The value of SCF was adjusted each year so that model simulated SWE on April 1st matched observed SWE at each snow pillow site. Thus SCF was again used to correct for gage deficiencies and seasonal differences in precipitation relationships.

Table 5. NWSRFS simulated and observed runoff comparisons for all periods of observed runoff and volume comparisons for the April through July period at Lower Willow Creek, Montana.

		Total Runoff for all Periods of Observed Data (mm)			Statistics for all Periods of Observed Data — Daily Errors (mm)			April-July Runoff (mm)		
		OBS	SIM	DIFF	RMS	AVG-ABS	r	OBS	SIM	DIFF
CALIBRATION PERIOD	1973	29.0	23.8	-5.2	.11	.06	.8274	25.7	19.8	-5.9
	1974	117.7	96.6	-21.1	.40	.28	.8857	113.5	88.0	-25.5
	1975	185.8	216.0	30.2	.54	.33	.9290	174.0	184.4	10.4
	1976	176.4	250.6	74.2	.38	.29	.9714	160.5	187.5	27.0
	1977	23.5	29.0	5.5	.06	.04	.8507	16.4	19.0	2.6
	1978	99.1	103.3	4.2	.20	.14	.8968	83.6	85.4	1.8
	1973-78	631.5	719.3	87.8	.32	.19	.9346	573.7	584.1	10.4
TEST PERIOD	1979	74.7	92.3	17.6	.21	.13	.9438	65.1	77.7	12.6
	1980	131.5	226.4	94.9	1.04	.44	.7319	118.8	198.6	79.8
	1981	96.1	103.2	7.1	.37	.21	.8870	86.5	84.6	-1.9
	1982	146.7	253.5	106.8	.79	.51	.9360	130.9*	219.8*	88.9*
	1983	97.8	124.4	26.6	.26	.16	.7808	66.9	77.2	10.3
	1984	139.9	128.1	-11.8	.46	.26	.8364	115.9	97.4	-18.5
	1979-84	686.7	927.9	241.2	.59	.28	.7904	584.1	755.3	171.2
	1973-84	1318.2	1647.2	329.0	.49	.24	.8502	1157.8	1339.4	181.6

* April data missing.

The simulated runoff hydrographs produced using the adjusted SCF values are presented in Figures 4, 5, and 6, along with observed runoff for the April through July period. The simulated runoff again exceeds observed runoff in most cases, while the timing of simulated and observed peaks match rather closely. The SCF values required to make simulated SWE match observed SWE on April 1st each year, are presented in Table 6 for the two zones used in the model. Also presented in Table 6 are statistical and runoff volume comparisons. The 1973 values are somewhat questionable, since October through December water year data were not available, and estimates of initial conditions On January 1st could affect these results. Omitting 1973, the range of SCF values required in the upper zone did not vary greatly from the value of 2.10 used in the calibration. In fact the average value for the remaining eleven years equaled 2.09. By the same criteria the SCF values needed in the lower zone were all above the 1.25 value obtained during calibration, some by almost three times.

The magnitude of the variations in SCF can be considered as a measure of how well the snow pillow readings represent the zones selected for modeling purposes. In other words, the Black Pine site represents the upper zone quite well, while the Combination site is considerably less representative of the lower zone. These results also suggest that April 1st SWE may not be a good index of spring runoff volume, especially from the lower zone where in most years some snowmelt has already occurred. The Combination SNOTEL site is near the upper boundary (5600' compared to 6100') of the lower zone and retains a snow cover longer than the majority of the area involved. Black Pine, on the other hand, represents the more uniform snow accumulation and melt conditions of the upper zone. Since snowpack conditions vary each year, the time of maximum snow accumulation in each zone may provide a better index of later snowmelt runoff. However, it would be more difficult to use in forecast procedures since it would occur at different times in each zone and for each year. The results could also suggest that the model calibration procedures may need modification.

D. Using SNOTEL SWE to Initiate the NWSRFS Model

Another approach that could improve model simulated results would be to use SNOTEL snow water equivalent data for updating the model whenever a forecast is desired. In this study, SWE as recorded at the pillow sites, on January 1st, February 1st, or March 1st was used to initiate the model. The model was then used to simulate April through July runoff, which was compared to observed runoff for the same period. The calibration values of model parameters were used, and the status of other conditions such as soil water storage in the various reservoirs was estimated. Drummond temperature and precipitation data for the years tested was again used as input for the forecast periods. In actual forecasting practice, the temperature and precipitation data would not be available, thus requiring the use of long-term averages, model generated, or some other method of producing the input data.

The four years selected for this test were those years which produced the greatest difference between simulated and observed runoff during the calibration and test periods. The 1982 year was not used because observed runoff was not available for April of that year for comparison purposes. The water years selected were 1975, 1976, 1980, and 1983. The simulated

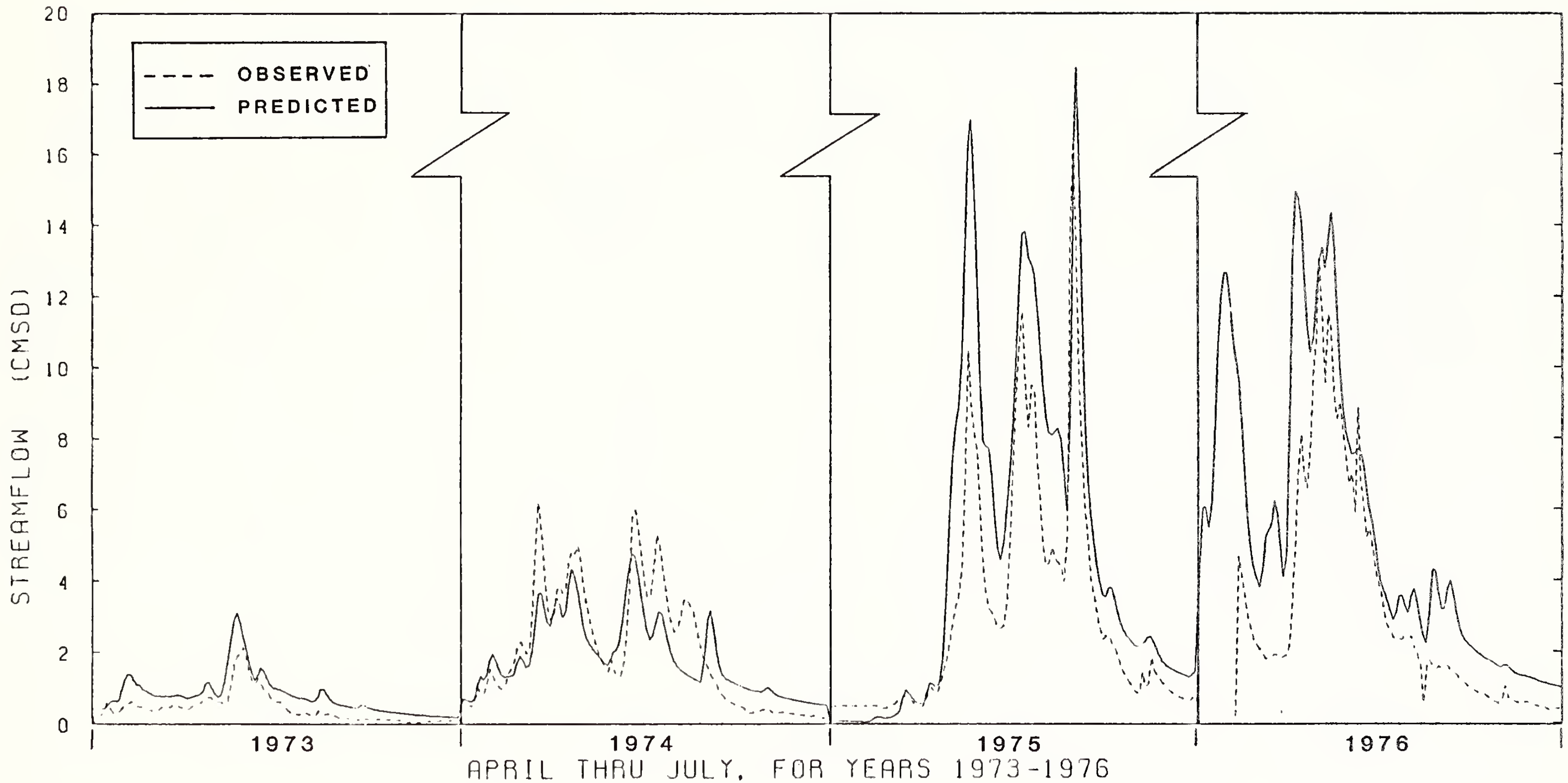

Figure 4. April through July observed and simulated streamflow at Lower Willow Creek, Montana for the 1973-1976 period. SCF is adjusted so that simulated SWE matches observed SWE at the snow pillow sites on April 1st each year.

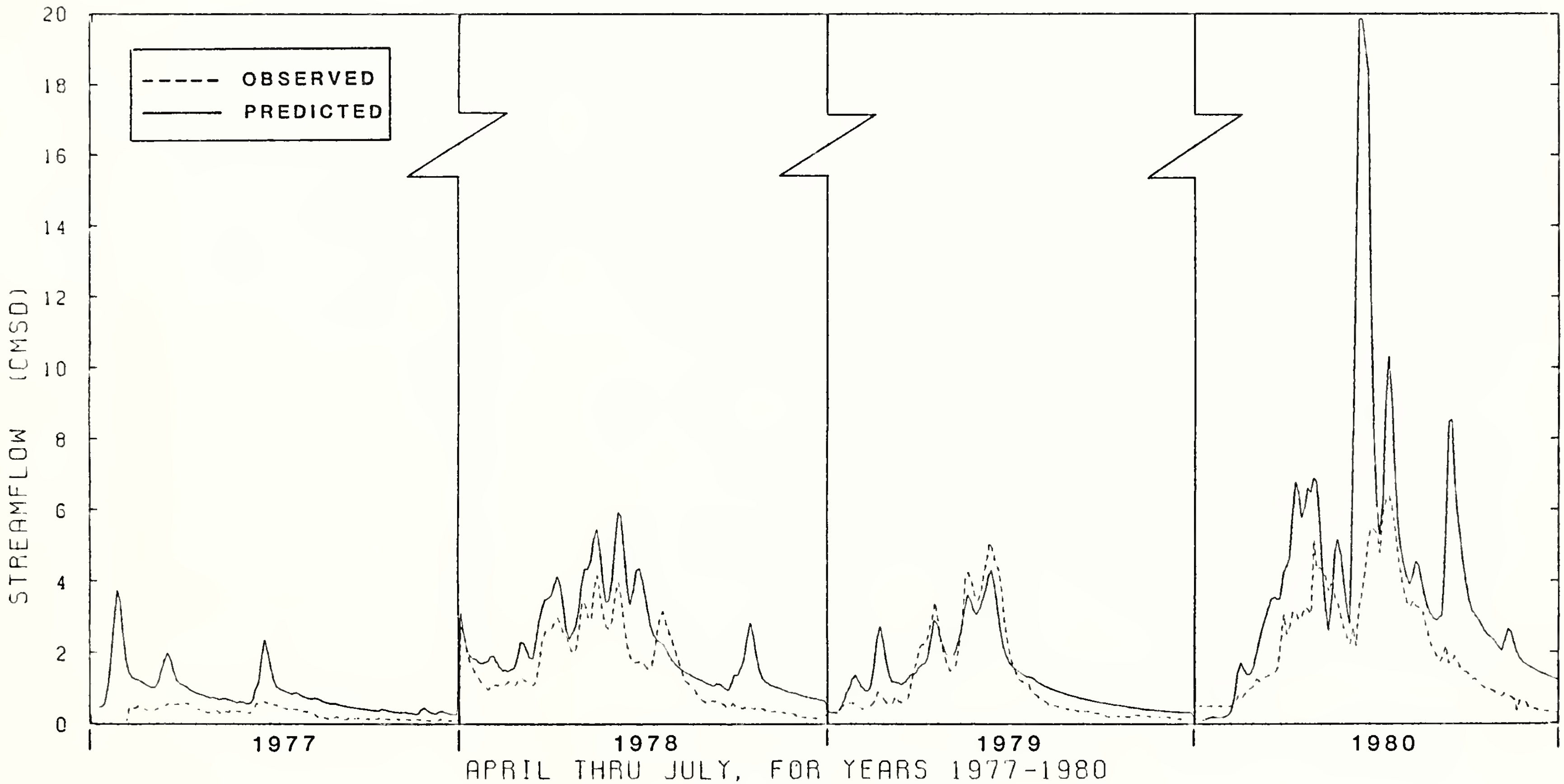

Figure 5. April through July observed and simulated streamflow at Lower Willow Creek, Montana for the 1977-1980 period. SCF is adjusted so that simulated SWE matches observed SWE at the snow pillow sites on April 1st each year.

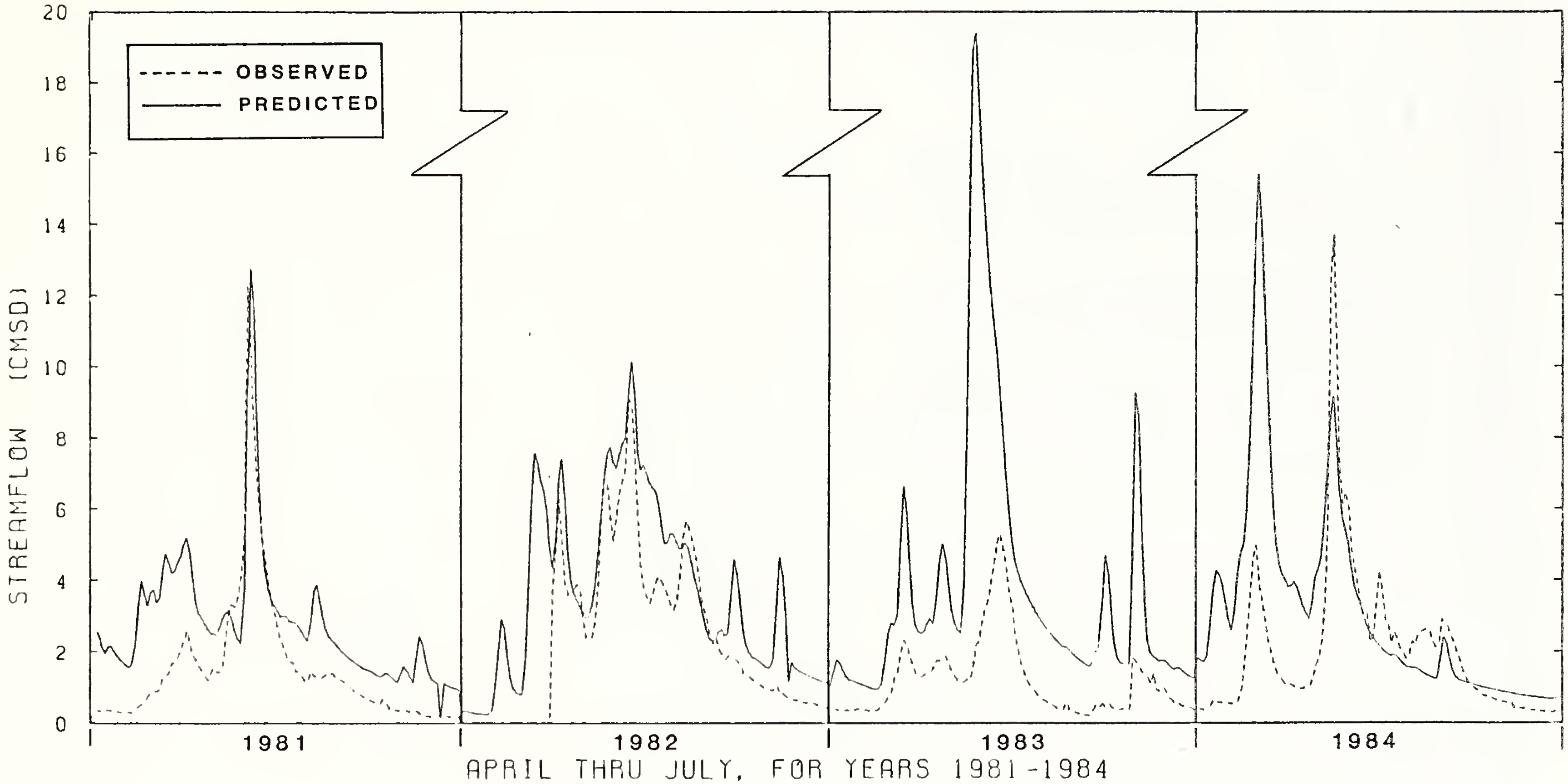

Figure 6. April through July observed and simulated streamflow at Lower Willow Creek, Montana for the 1981-1984 period. SCF is adjusted so that simulated SWE matches observed SWE at the snow pillow sites on April 1st each year.

Table 6. Snow correction factors (SCF) required to match observed SWE at the Combination an Black Pine sites, and simulated runoff compared to observed runoff at Lower Willow Creek, Montana.

	SCF		April-July Runoff (mm)			Daily Errors (mm)		
	Lower Zone	Upper Zone	OBS	SIM	DIFF	RMS	AVG-ABS	r
1973	5.90	3.20	25.7	44.4	18.7	.16	.12	.9353
1974	1.75	1.93	113.5	103.7	-9.8	.35	.26	.9109
1975	1.71	2.35	174.0	262.7	88.7	1.06	.72	.9262
1976	1.90	2.05	160.5	243.6	83.1	.90	.59	.9194
1977	2.84	2.46	16.4	37.5	21.1	.18	.13	.9125
1978	1.75	2.42	83.6	125.7	42.1	.34	.25	.9108
1979	1.56	1.71	65.1	74.0	8.9	.18	.13	.9433
1980	1.76	2.14	118.8	235.5	116.7	1.35	.59	.7324
1981	2.93	2.02	86.5	156.5	70.0	.58	.45	.8628
1982	1.30	1.55	130.9*	173.5*	42.6*	.45	.31	.9452
1983	3.42	2.35	66.9	213.6	146.7	1.22	.61	.7520
1984	3.25	2.05	115.9	174.1	58.2	.90	.46	.6610
Total	24.17	23.03						
Average	2.20	2.09						

* April data missing.

runoff that was produced when the model was initiated on January 1st of the four test years and the observed runoff for corresponding years is presented in Figures 7, 8, 9, and 10. Plots of the runoff traces produced when the model was initiated on February 1st and March 1st are not presented. These traces were essentially the same as the January 1st trace, in timing, but were of greater magnitude in volume, especially peak values. Comparisons of runoff volume and statistical measures are presented in Table 7 for the various starting dates. Also included for comparison are the results obtained during the calibration or test periods.

In all cases tested, the model simulated runoff exceeded observed runoff. It is interesting to note that snowpack conditions on the earliest starting date (January 1st) produced the best results, followed by the next earliest date. Also, this updating scheme improved results over those obtained in the calibration and test runs in only the 1976 water year. However, results were essentially the same in the January 1st starting date runs for 1975 and 1983. It would be interesting to see if results were improved using the procedure described in part B, if SCF were changed so that simulated SWE matched observed SWE on January 1st rather than April 1st. Results could be dramatically different, since April 1st conditions were noted to be nonrepresentative of the lower zone for that study.

Two other factors that could have significant impact on the simulated results are the method of calibration used and the noncontinuous data base available. If the model had been calibrated on the snow pillow data prior to calibration based on runoff, the SWE values may have been a better index of subsequent runoff. The problems associated with initiating a model run without a continuous record of input data such as runoff, soil moisture storage, etc., could also significantly affect the simulation results. In all cases where data are not available, the status of the various water storage and conveyance compartments must be estimated, thus impacting the results accordingly.

E. Using the NWSRFS Model with Daily Snow Pillow SWE in Place of HYDRO-17 Simulated SWE

One of the great advantages of the SNOTEL sytem over the traditional snow course surveys is the ability to obtain real time data rather than biweekly or monthly SWE readings. Although the NWSRFS model was not originally designed to use SNOTEL information as input, it is possible to modify the normal procedures and make use of this more timely data. The procedure used in this study was to replace the simulated snow plus rain output of the HYDRO-17 subroutine with actual daily snowmelt determined from the snow pillow readings plus Drummond precipitation. In other words, only the Sacramento soil moisture accounting and unit hydrograph submodels were used with the SNOTEL and Drummond precipitation as input. All model parameters remained the same as those established during the calibration period.

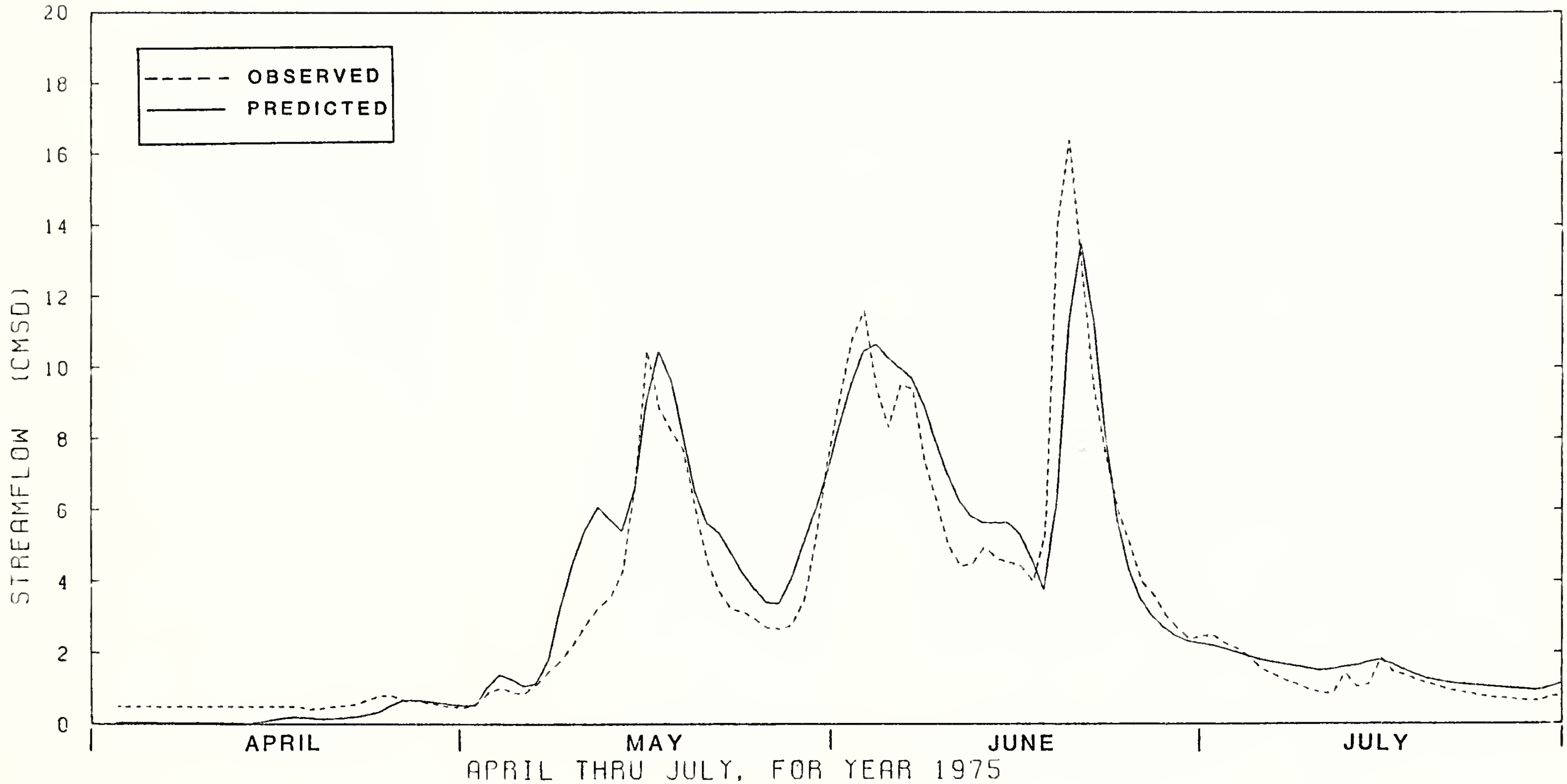

Figure 7. April through July observed and simulated streamflow at Lower Willow Creek, Montana for 1975. Model initiated on January 1st using observed SWE at the snow pillow sites.

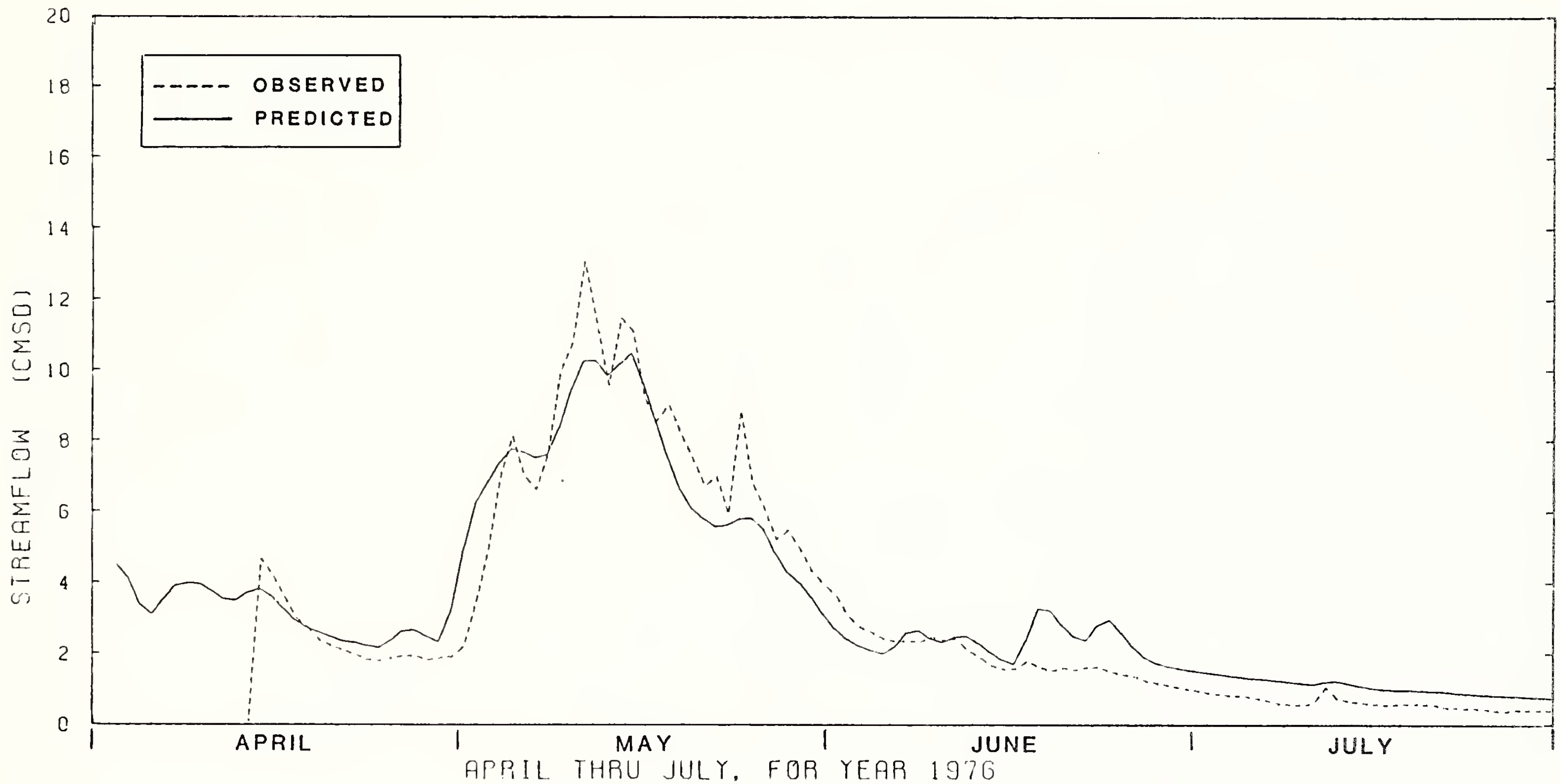

Figure 8. April through July observed and simulated streamflow at Lower Willow Creek, Montana for 1976. Model initiated on January 1st using observed SWE at the snow pillow sites.

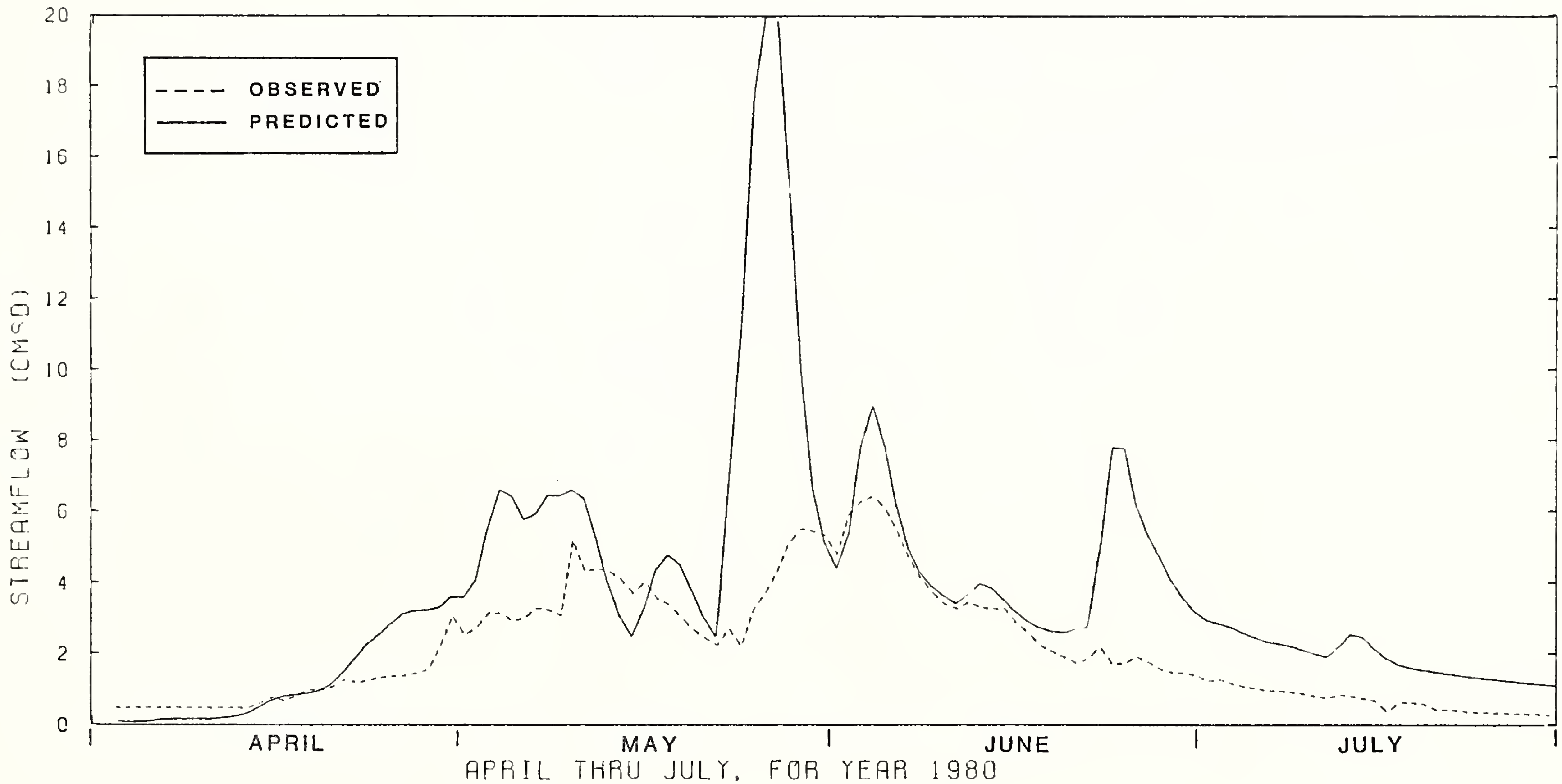

Figure 9. April through July observed and simulated streamflow at Lower Willow Creek, Montana for 1980. Model initiated on January 1st using observed SWE at the snow pillow sites.

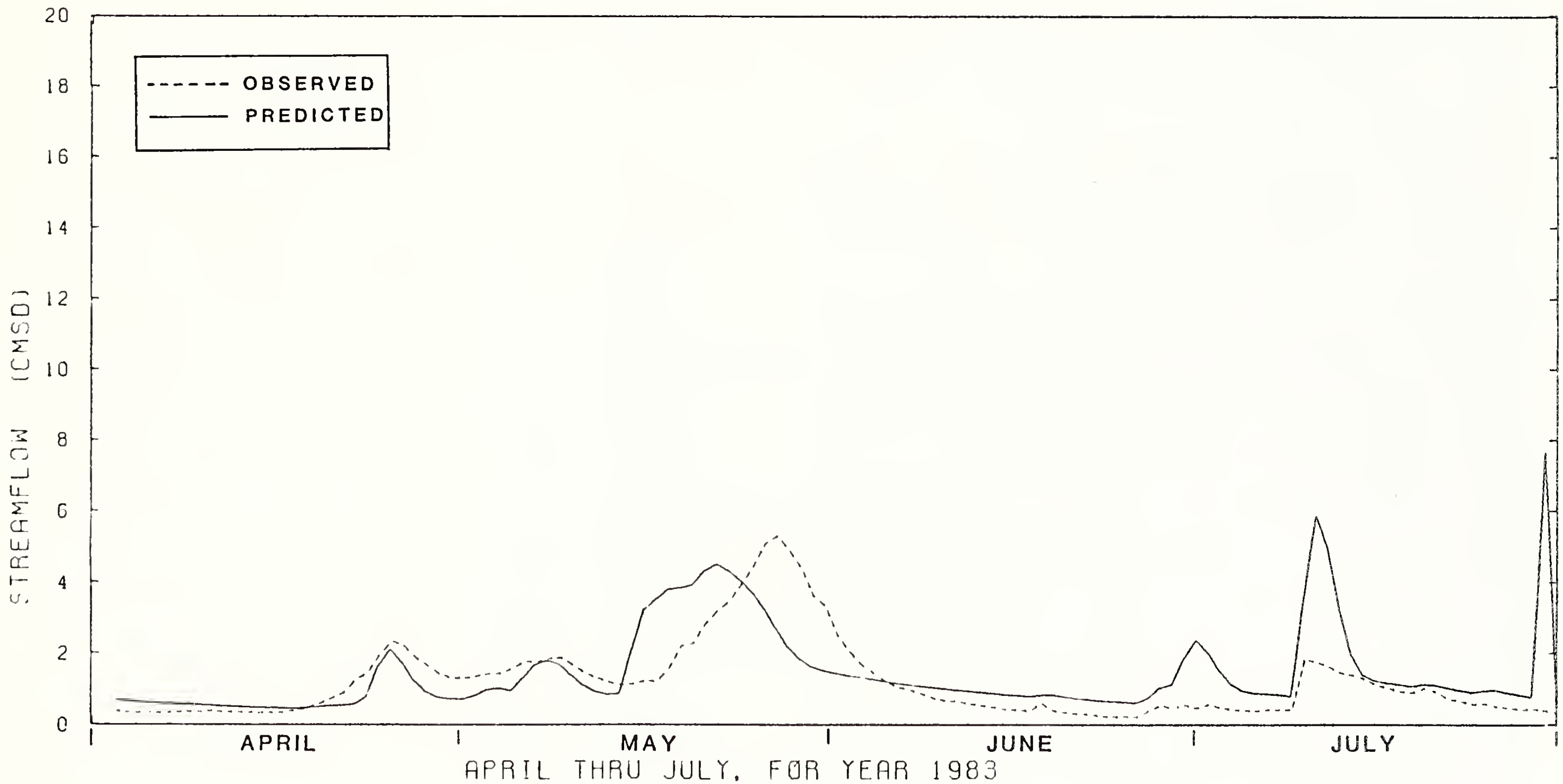

Figure 10. April through July observed and simulated streamflow at Lower Willow Creek, Montana for 1983. Model initiated on January 1st using observed SWE at the snow pillow sites.

Table 7. Runoff volume and statistical comparisons for various model-run starting dates at Lower Willow Creek, Montana.

		April-July Runoff (mm)			Daily Errors (mm)		
		OBS	SIM	DIFF	RMS	AVG-ABS	r
1975	JAN 1st	174.0	184.8	10.8	.56	.34	.9241
	FEB 1st	174.0	218.6	44.6	.70	.48	.9298
	MAR 1st	174.0	215.8	41.8	.69	.46	.9278
	CALIB.	174.0	184.4	10.4	.54	.33	.9290
1976	JAN 1st	160.5	170.9	10.4	.35	.26	.9726
	FEB 1st	160.5	171.0	10.5	.34	.25	.9743
	MAR 1st	160.5	180.7	20.2	.40	.30	.9653
	CALIB.	160.5	187.5	27.0	.38	.29	.9714
1980	JAN 1st	118.8	208.4	89.6	1.26	.62	.7027
	FEB 1st	118.8	215.8	97.0	1.32	.66	.7066
	MAR 1st	118.8	227.5	108.7	1.45	.72	.6991
	TEST	118.8	198.6	79.8	1.04	.44	.7319
1983	JAN 1st	66.9	77.1	10.2	.35	.22	.6879
	FEB 1st	66.9	77.4	10.5	.35	.22	.6873
	MAR 1st	66.9	93.7	26.8	.43	.28	.6988
	APR 1st	66.9	132.3	65.4	.62	.42	.8253
	TEST	66.9	77.2	10.3	.26	.16	.7808

The above procedure was tested on the 1975 water year. The model runs were initiated using April 1st watershed conditions as determined from SNOTEL data and calibration runs. Simulated and observed April through July runoff was used for calibration. Model parameters as determined for the calibration period (Table 4) were used in the first run and results are presented in Figure 11 and Table 8. Both timing and volume are noted to be quite different than observed. A second run was made in an attempt to correct these descrepancies. The precipitation adjustment factor PXADJ included in the Sacramento soil moisture submodel was adjusted to compensate for the differences in runoff volume noted during the first run. Results of the second run are presented in Figure 12 and Table 8. As noted the observed and simulated runoff volumes are essentially identical, the daily errors are smaller, and the correlation coefficient r has increased. However, the timing of runoff peaks is still not as good as that obtained during the calibration runs using HYDRO-17 results rather than observed snow pillow melt. Part of the differences observed could be due to the calibration being based on runoff rather than snow pillow data as previously mentioned. However, the large errors noted at the end of May and first of June, may be greater than one could adjust for by changing soil moisture reservoir sizes and transmission times. If this were the case, it would again indicate that either the snow pillow sites do not represent the zones selected, or Drummond precipitation is not a good measure of precipitation on the watershed at this time. In either case, the importance of on-site climatological data and representative SNOTEL sites is imperative for increased modeling accuracy.

F. Discussion

Other than the calibration and test period results, the outcome of the other studies was less than anticipated. However, the procedures were tested and proved to be operationally possible, and several main problems were identified that could be avoided in future studies. The first problem relates to the study site and the data set that was available. The lack of a continuous streamflow record made it difficult to develop calibration parameters related to baseflow conditions. Also, the discontinuous record made it necessary to assume initial watershed conditions at the beginning of each run and could have added to the magnitude of the errors.

The second problem seemed to be a product of the method used to calibrate the model. In this case, the entire model was calibrated with respect to observed runoff. This may not have resulted in any problems were it not for the attempts to use actual snow water equivalent and snowmelt data as inputs for initiating and updating the model. A better approach might have been to calibrate the HYDRO-17 submodel with respect to data available at the snow pillow sites. Then using the calibration parameter values thus obtained for HYDRO-17, the parameter values in the Sacramento soil moisture accounting and unit hydrograph submodels could be adjusted (calibrated) with respect to observed streamflow. The tests described in sections C, D, and E should then be more meaningful and hopefully better results would be obtained.

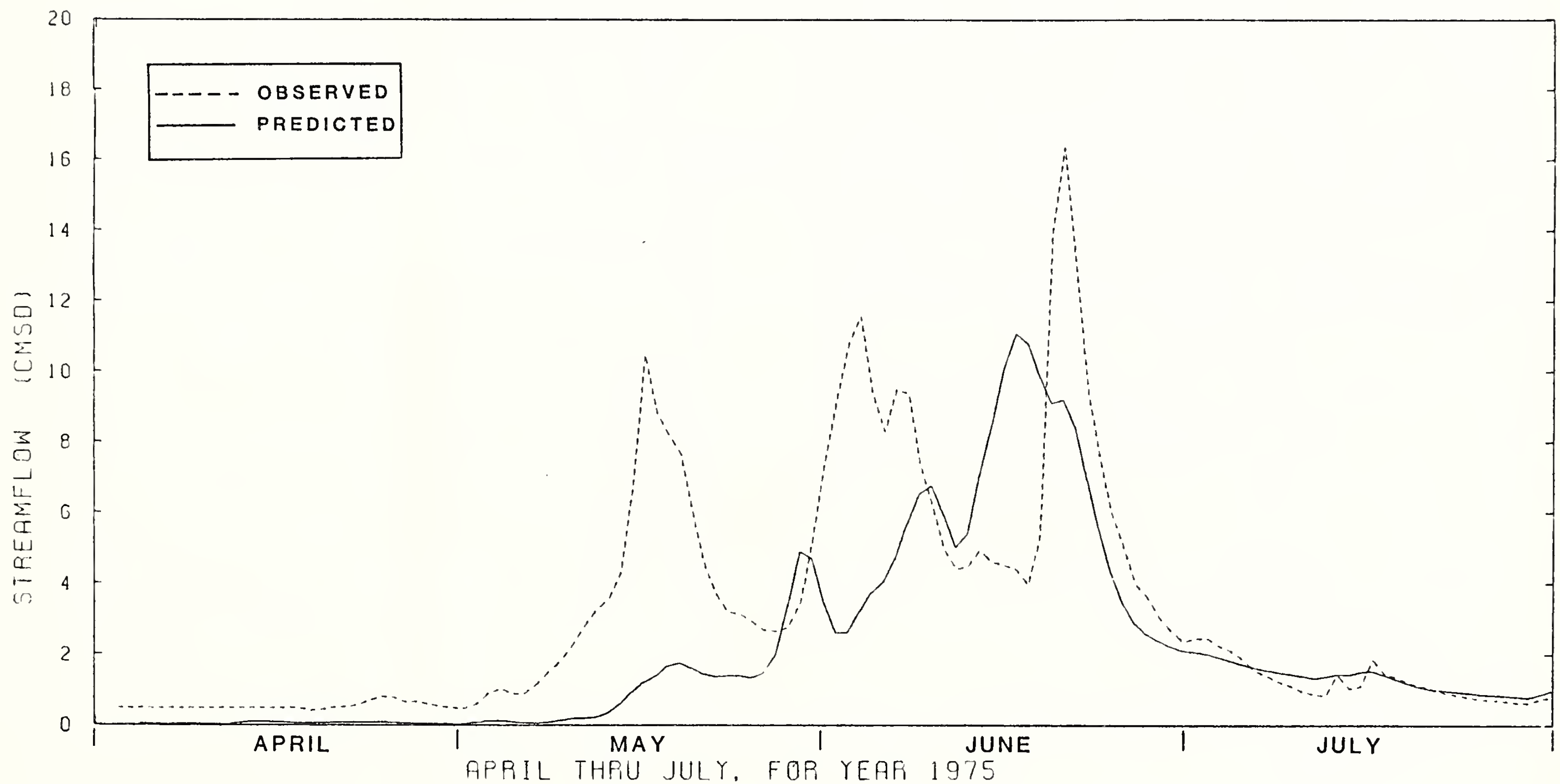

Figure 11. April through July observed and simulated streamflow at Lower Willow Creek, Montana for 1975. Model initiated April 1st using calibration parameter values, observed SWE, and actual snowmelt at the snow pillow sites plus Drummond rainfall as input.

Table 8. Simulated and observed runoff comparisons for the April through July periods obtained from actual snowmelt measurements at the Black Pine and Combination snow pillow sites at Lower Willow Creek, Montana.

		PXADJ		April-July Runoff (mm)			Daily Errors (mm)		
		Lower Zone	Upper Zone	OBS	SIM	DIFF	RMS	AVG-ABS	r
1975	(1)	1.000	1.00	174	115.6	-58.4	1.26	.77	.6598
	(2)	1.420	.800	174	174.2	0.2	1.10	.73	.7550

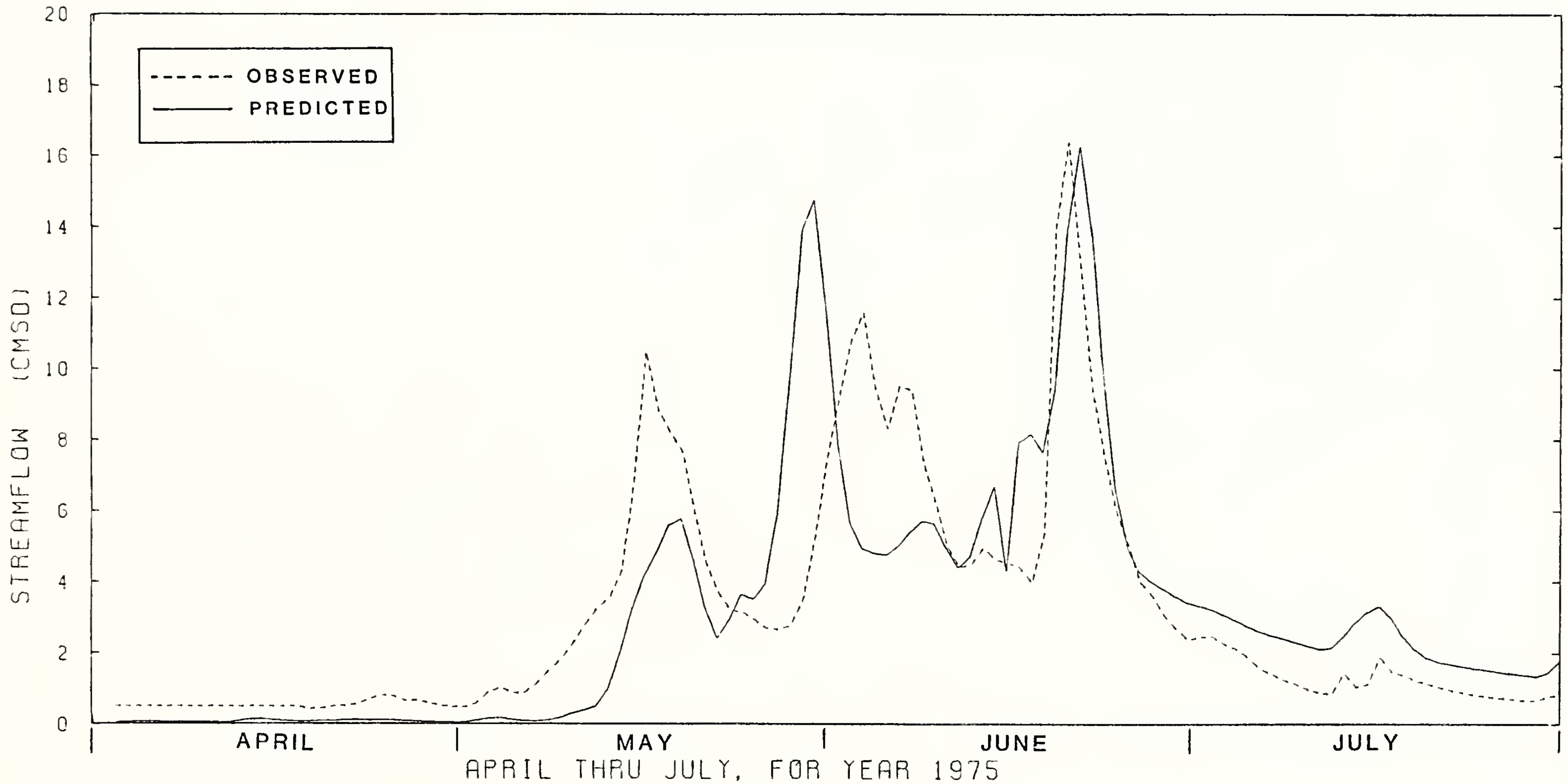

Figure 12. April through July observed and simulated streamflow at Lower Willow Creek, Montana for 1975. Model initiated April 1st using "best fit" parameter values, observed SWE, and actual snowmelt at the snow pillow sites plus Drummond rainfall as input.

Section II SNOTEL Precipitation Data Fluctuation Study

In response to the concern expressed about irregularities in the SNOTEL precipitation data, an analytical review of the problem was begun. The review consisted of examining the physics of the sensing system and a statistical analysis of selected SNOTEL precipitation and temperature data.

A. Statistical Analysis

The West National Technical Center (WNTC) supplied a printout of data collected between July 18-23, 1985, from six SNOTEL sites in Oregon. The collection interval was during a period of no precipitation. The statistical analysis consisted of regressing accumulated precipitation against air temperature, plotting the resulting relationship, and testing the hypothesis that no statistically significant correlation exists between air temperature and sensed precipitation. A summary of the regression analysis is given in Table 9. Plots of the precipitation-temperature relationship are shown in Figures 13 through 18. Some speculative conclusions concerning each site based on an examination of the respective plots and regression results are as follows:

1. Hogg Pass, Oregon. The 23 precipitation readings measured by the SNOTEL sensors during the July test run ranged from a low value of 69.7 to a high of 70.4, a difference of 0.7 inches. The mean precipitation value was 70.0 inches. During this period, the sensor error of -0.3 to +0.4 inches fell outside the system specifications of ±0.3 inches for precipitation measurement accuracy. The relationship between precipitation and temperature was highly significant with a correlation coefficient of -0.927 and an F statistic value of 128.3 with an associated probability of obtaining this value by chance of less than 0.001 percent. It appears that this relationship would point towards a real temperature dependency with the precipitation measuring system. If this hypothesis is correct, the precipitation values could be brought within the tolerance limits of ±0.3 inches by adding a temperature correction to the measured values of precipitation. Thus, the corrected precipitation becomes:

$$P_c = P_m + C_T \qquad (1)$$

where:

P_c = the corrected precipitation in inches;

P_m = the SNOTEL measured precipitation in inches;

C_T = 0.619 - 0.033T in inches; and

T = the SNOTEL measured ambient air temperature in degrees Celsius.

Table 9. Summary of regression analysis results for six Oregon SNOTEL sites using July 18-23, 1985 test data.

Site name	Correlation coefficient R	Probability of nonsignificant relationship (percent)	Range of accumulated precip. (inches) Ave	Min	Max	Δ	Range of temperature (° C) Ave	Min	Max	Δ	Temperature correction equation ($C_T = a + b_T$) a	b
1 Hogg Pass	-0.927	<.001	70.0	69.7	70.4	0.7	18.9	9.5	30.7	21.2	0.619	-0.033
2 Jump Off Joe	-0.436	.244	74.2	68.3	74.8	6.5	20.9	10.5	32.0	21.5	--	--
3 Daly Lake	-0.937	<.001	78.5	77.2	79.3	2.1	22.7	11.6	32.4	20.8	2.568	-0.113
4 Marion Forks	0.073	69.8	72.7	72.3	73.1	0.8	16.6	9.1	34.7	25.6	--	--
5 Little Meadows	0.951	<.001	11.1	10.7	11.7	1.0	19.6	10.0	29.9	19.9	-1.103	0.056
6 Santiam Junction	-0.003	98.2	66.1	66.0	66.2	0.2	20.0	7.7	34.1	26.4	--	--

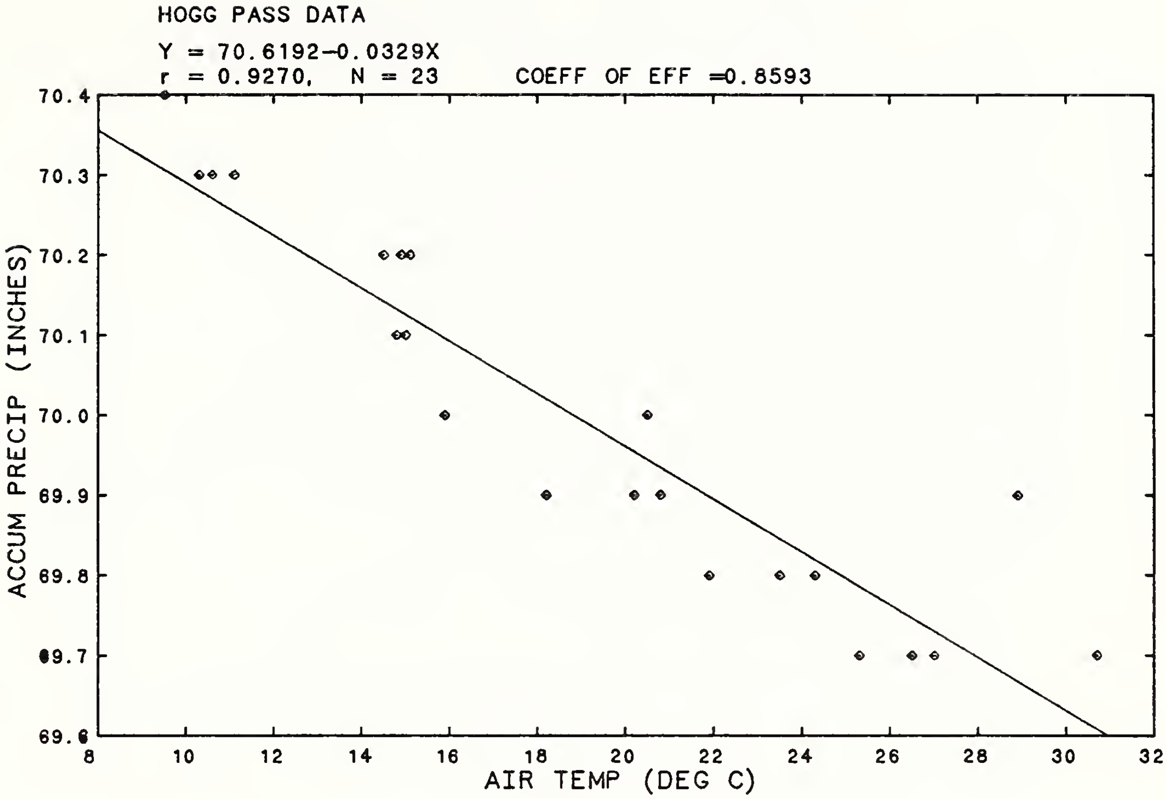

Figure 13. Plot of precipitation-temperature data for Hogg Pass, Oregon SNOTEL site.

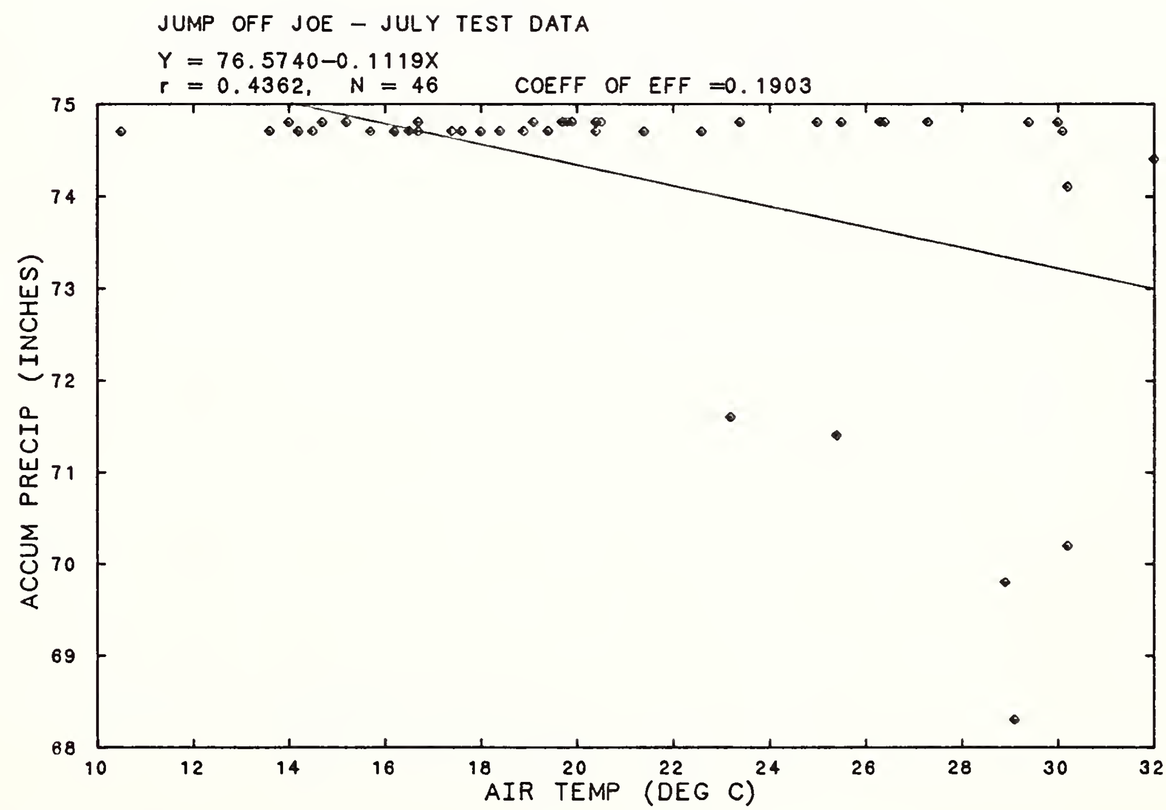

Figure 14. Plot of precipitation-temperature data for Jump Off Joe, Oregon SNOTEL site.

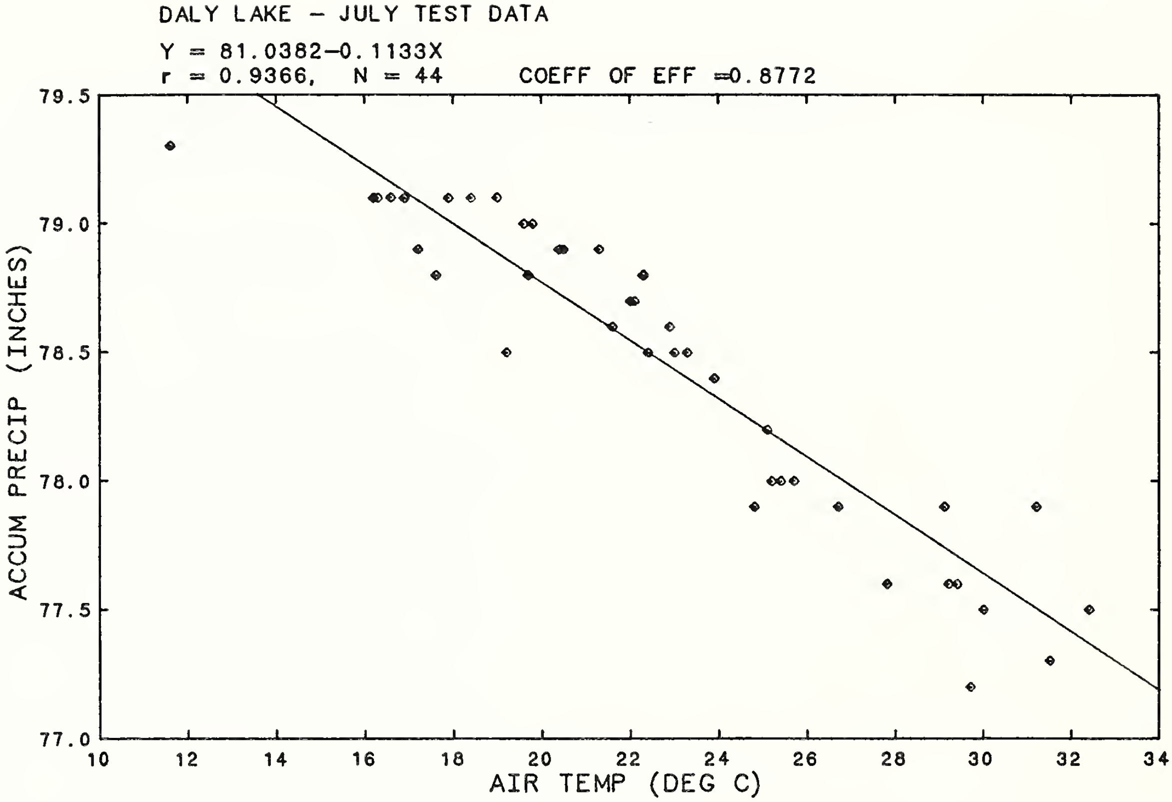

Figure 15. Plot of precipitation-temperature data for Daly Lake, Oregon SNOTEL site.

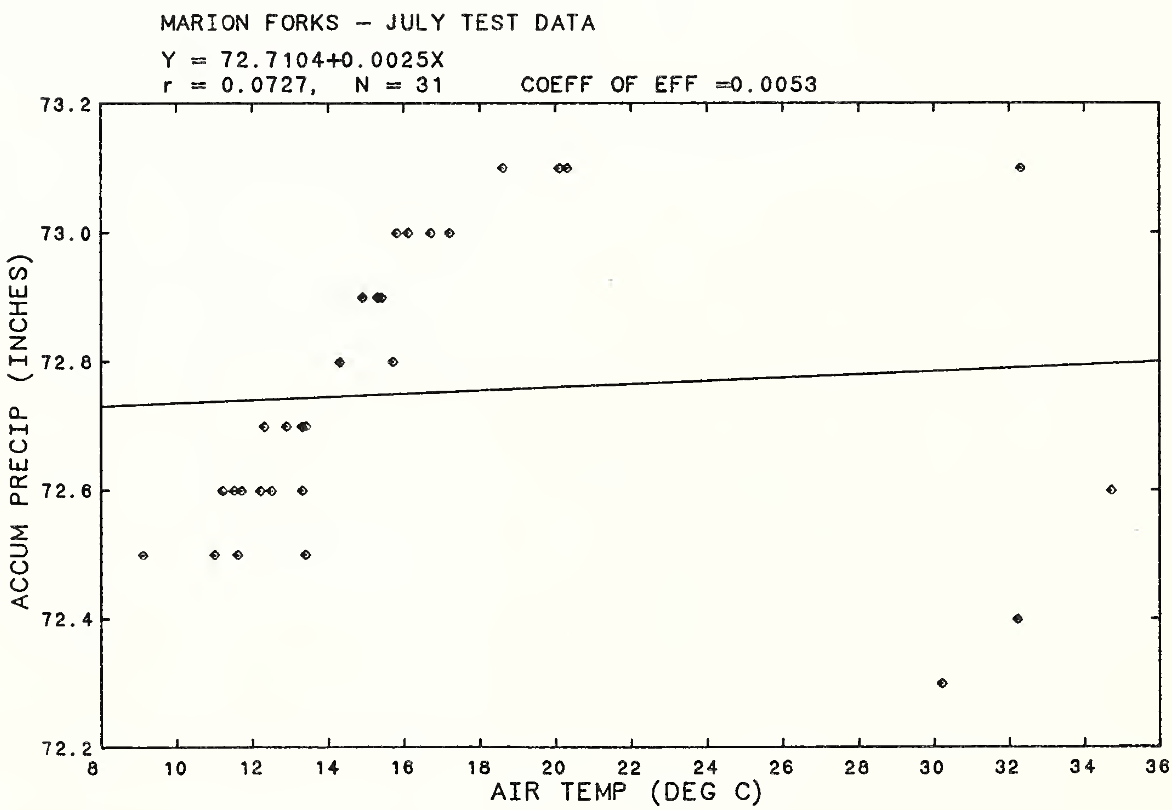

Figure 16. Plot of precipitation-temperature data for Marion Forks, Oregon SNOTEL site.

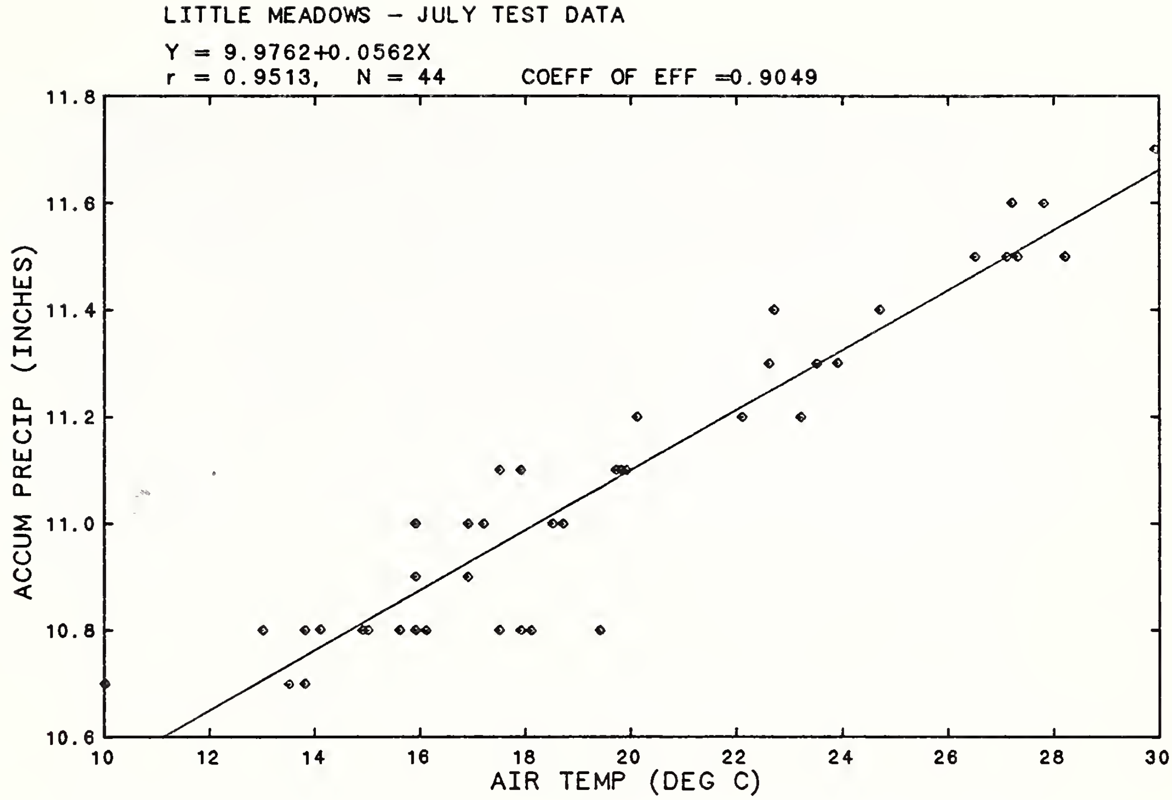

Figure 17. Plot of precipitation-temperature data for Little Meadows, Oregon SNOTEL site.

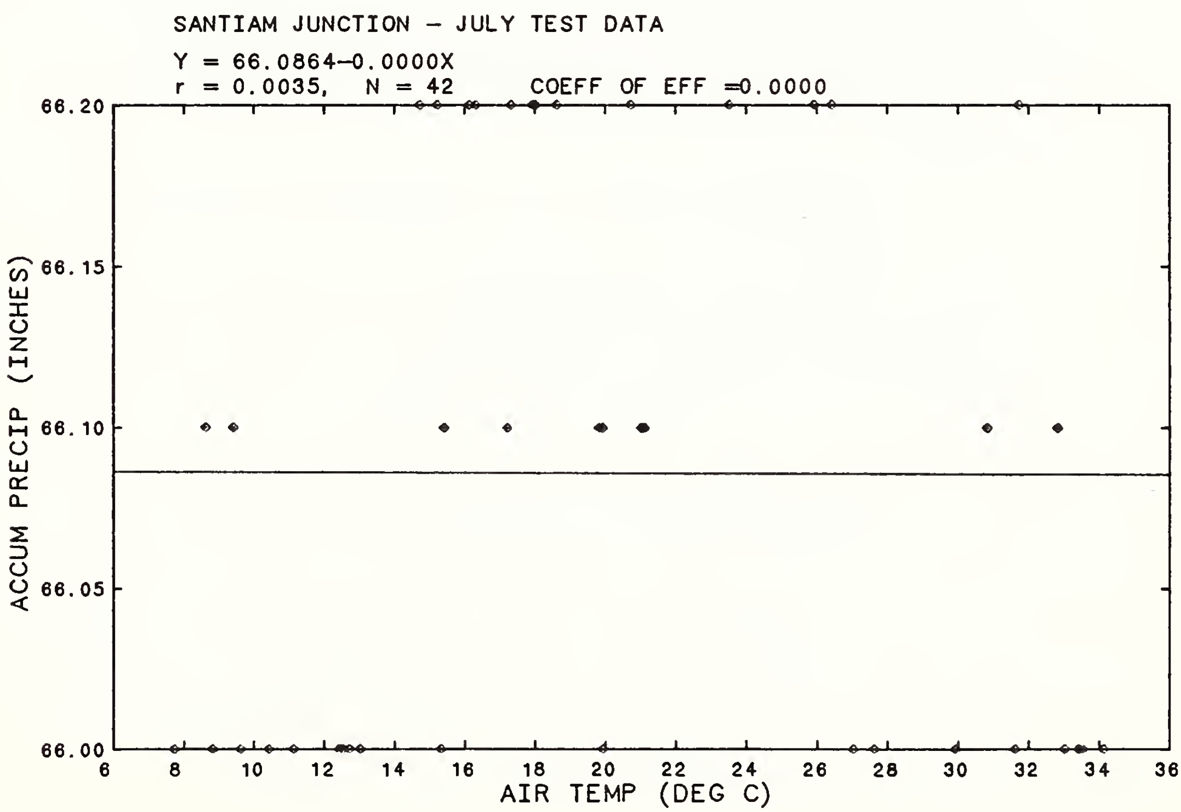

Figure 18. Plot of precipitation-temperature data for Santiam Junction, Oregon SNOTEL site.

The intercept value of 0.619 in the equation for calculating C_T is obtained by subtracting the mean value of the accumulated precipitation from the regression equation relating accumulated precipitation with Celsius air temperature. The specific temperature correction should be adopted only after it is verified by completing a more comprehensive analysis utilizing much more data.

2. **Jump Off Joe, Oregon.** The regression analysis for this site revealed a significant temperature dependency in the precipitation measurement. However, examination of the plot of the precipitation versus temperature, Figure 14, reveals that there would be no temperature dependency if five measurements were ignored. These five points all occur in the lower right section of the plot and indicate that the SNOTEL telemetry or precipitation transducer may become erratic when some threshold temperature, in this case T greater than 22 degrees Celsius, is reached. It appears that the precipitation measurements are within system specifications with no temperature dependency for T less than 22 degrees Celsius. A definitive explanation of the above behavior will require analysis of much more data and possibly a physical examination of the equipment and site installation.

3. **Daly Lake, Oregon.** The regression analysis for the Daly Lake site data revealed a highly significant precipitation-temperature relationship. The correlation coefficient was -0.937 with a probability of less than 0.001 percent of this occurring by chance. The values of measured precipitation deviated about the mean from -1.27 to +0.83 inches. The values could be corrected for temperature by calculating a correction factor as follows:

$$C_T = 2.568 - 0.113T \tag{2}$$

where:

T = the SNOTEL measured air temperature at Daly Lake in degrees Celsius.

This correction would probably bring the corrected values into the accuracy specifications of the system of ± 0.3 inches of precipitation. This should be verified by analyzing more data from this site. The precipitation-temperature relationship does appear to be quite consistent and thus amenable to correction.

4. **Marion Forks, Oregon.** The regression analysis revealed a significant precipitation-temperature relationship. The measured values of precipitation did deviate about their mean value by -0.45 to +0.35 inches which did not meet the system specifications for accuracy of ± 0.3 inches. Examination of Figure 16 reveals that a high positive temperature dependency may exist if four values that occurred with temperatures greater than 30 degrees Celsius were eliminated from the analysis. This may be due to air in the lines connecting the manometer to the precipitation can. This speculation would have to be verified by further analysis and a site inspection.

5. **Little Meadows, Oregon.** The regression analysis for this site identified a highly significant temperature dependency associated with the SNOTEL precipitation sensors. The positive correlation coefficient of 0.951 had a probability of occurring by chance of less than 0.001 percent. Examination of Figure 17 along with the results of the regression analysis suggest either an air bubble in the lines connecting the measuring manometer with the precipitation can or a thermally dependent pressure transducer installed in the measuring manometer. Since temperature caused variations in manometer levels of 1 inch or more have been observed, an air bubble in the piping system is most probable. A site inspection would be required to verify this. A temperature correction could be made that may bring the measured values within system specifications. Based on the 44 observations obtained from the July test data for this site, the temperature correction is:

$$C_T = -1.103 + 0.056T \tag{3}$$

where:

T = the SNOTEL air temperature measured at the Little Meadows, Oregon site in degrees Celsius.

Additional analysis is required to verify and confirm the above hypothesis and relationship.

6. **Santiam Junction, Oregon.** The analysis of data from this site revealed that it operated well within system specifications. There appeared to be no temperature correlation with the precipitation measurements. The accumulated precipitation measurements varied about the mean value of 66.1 inch by ± 0.1 inch.

The analysis results for the July 1985 test data for six Oregon sites may be summarized as follows:

1. Two sites, Marion Forks and Santiam Junction, appeared to be operating according to specifications.

2. Two sites, Hogg Pass and Daly Lake, appeared to have thermally influenced sensing systems that could be corrected by determining and applying a temperature correction.

3. One site, Little Meadows, had a high temperature correlation that most likely was caused by installation characteristics.

4. One site, Jump Off Joe, required more investigation to identify and correct apparent inconsistencies in the precipitation data.

5. Further analysis must be carried out to confirm the above conclusions and screen all SNOTEL sites in the western United States.

B. Field Study

There are several factors that could be causing the diurnal fluctuations in precipitation gage readings from the SNOTEL sites. The problems seem to be a function of temperature and may be in the electronic equipment for transmitting or receiving the data, the variation in expansion of the fluid or solid parts of the system, or in the installation procedures themselves. An analysis of the data (see section II-A above for preliminary report) will provide an indication of the number of sites experiencing fluctuations, the magnitude of the errors, and a method of correcting some of the data records. However, the analysis will probably not identify the cause of the problem or make corrections at the point of the problem. This will require a study of conditions encountered at the field site. Plans for this field study have been developed, and initial steps have been taken to isolate the problem.

Briefly, the plan consists of the following elements:

1. Select two sites for intensive monitoring of temperatures within the gages, manometer, shelter, electronics, and fluid. The two sites tentatively selected are the Bureau of Reclamation weather station near the Federal Building in Boise, and an accessible SNOTEL site that exhibits the fluctuations such as the Mores Creek site near Idaho City.

2. Install temperature sensors as discussed above along with Robinson-Halpern and Druck pressure transducers. The pressure transducers will be placed in parallel with the existing system in the shelter, and a Druck transducer will be placed at the precipitation gage location also.

3. Record all data at frequent (at least hourly) intervals on the Bureau of Reclamation's recording system in Boise, and on a portable automatic data acquisition system at the Mores Creek site.

4. Analyze the data collected during the 1986 summer period to determine the source of the daily fluctuations.

5. Report results to SCS and BuRec in FY86 annual report.

At this stage, the equipment has been ordered, the two study sites have been tentatively selected, and a preliminary analysis of the magnitude of possible errors due to the variable expansions of fluid and gage have been conducted. The analysis was based on assumed temperature changes, and is not considered adequate for inclusion until actual temperature variations are known. Indications are that expansion and contraction do not cause fluctuations of the magnitude observed, however.

Section III Instrumentation

Continuation of the Upper Sheep Creek study on the Reynolds Creek Experimental Watershed has provided the opportunity to monitor the operation of several types of climatological field sensors. Some of the sensors have been in continuous operation for over two years. Comments concerning the sensor reliability and data quality are noted below.

A. Soil Moisture

The gypsum soil moisture blocks have continued to provide reliable gross indication of soil moisture for the second year without any failures. However, these devises are not suitable for precise soil moisture measurements.

B. Humidity

The Texas Electronics model TH-2013* humidity sensor has continued to provide trouble free high quality data for the second year.

C. Wind Run

The Belfort catalog # 5-349C-5 anemometer needs the 1/60 mile switch contacts burnished on a yearly basis.

D. Pressure Transducer

Twenty-four Druck model PDCR 10/D pressure transducers have been installed in piezometer tubes for approximately one year and have performed very well, exhibiting good resolution and negligible drift. The transducers installed in weirs have continued to function exceptionally well.

---

*Product names are supplied for reader convenience only and in no way constitute endorsement or recommendation for use by the U.S. Department of Agriculture, Agricultural Research Service.

ACKNOWLEDGEMENT

We would like to acknowledge and express our appreciation to Bernie Shafer, Phillip Farnes, Art Crook, Don Jensen, and Gerald Beard of the SCS, Dan Lute of the BuRec, George Leavesly and Linda Saindon of the USGS, and the data processing staff and Shari Hennefer of the NWWRC-ARS, for their assistance and suggestions in obtaining data, calibrating the model, and producing this report.